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**(54) OPTICAL WAVEGUIDE STRUCTURE**

**OPTISCHER WELLENLEITER**

**STRUCTURE DE GUIDE D'ONDES OPTIQUE**

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- **APPLIED PHYSICS LETTERS, 16 JAN. 1995, USA, vol. 66, no. 3, ISSN 0003-6951, pages 274-276, XP002006429 MARX J M ET AL: "Low-loss strain induced optical waveguides in strontium barium niobate (Sr/sub 0.6/Ba/sub 0.4/Nb/sub 2/O/sub 6/) at 1.3 mu m wavelength" cited in the application**
- **PATENT ABSTRACTS OF JAPAN vol. 011, no. 354 (P-638), 19 November 1987 & JP 62 133423 A (SUMITOMO SPECIAL METALS CO LTD), 16 June 1987,**
- **PATENT ABSTRACTS OF JAPAN vol. 013, no. 180 (P-864), 27 April 1989 & JP 01 010212 A (NIPPON TELEGR & TELEPH CORP), 13 January 1989,**

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**Description****Field of the invention**

- 5 [0001] This invention relates to an optical waveguide structure in which an electric field may be applied to achieve electro-optic effects, and has particular application to optical fibres.

**Background**

- 10 [0002] It is well known that lithium niobate changes its optical characteristics in response to an applied electric field and can be used as an electro-optic modulator or a non-linear optical element, particularly in an optical fibre. However, it has a number of drawbacks, particularly high coupling losses when coupled to a standard fibre and a low-photorefractive damage threshold, which have prompted an investigation of the electro-optic effects of glassy materials and in particular silica.

- 15 [0003] Thermally assisted poling of silica has been known to induce electro-optic coefficients in both bulk silica and optical fibres, and reference is directed to L. Li & D. N. Payne "Permanently-Induced Linear Electro-Optic Effect in Silica Optical Fibres, Dig. Conf. Integrated and Guided Wave Optics, 1989 OSA, Paper TuAA2-1 (1989). However, the coefficient induced in this way is not sufficiently high to allow practical devices to be constructed.

- 20 [0004] It has recently been found that germanosilicate fibre, which is photosensitive to u.v. light, can be photo-excited with incident u.v. radiation to produce an electro-optic coefficient comparable to that of lithium niobate. Reference is directed to T. Fujiwara, D. Wong, Y. Zhao, S. Fleming, V. Grishina & S. Poole, "UV-Excited Poling and Electrically Tunable Bragg Gratings in a Germanosilicate Fibre", Postdeadline Paper OFC '95 (Feb '95). The u.v. technique has a significant further advantage over thermal poling in that it permits the writing of gratings and other structures in the fibre.

- 25 [0005] In order to achieve a sufficiently high applied field for the fibre, it has previously been proposed to modify a conventional germanosilicate fibre which has a Ge doped core of relatively high refractive index surrounded by SiO<sub>2</sub> cladding of relatively low refractive index, so as to include longitudinal apertures in the cladding to receive electrodes in the form of metal wires running generally parallel to the core on opposite sides. By placing the electrodes close to the core, within the cladding, a sufficiently high field can be developed across the core in order to induce changes in the refractive index of the core. Reference is directed to S. C. Fleming, T. Fujiwara and D. Wong "UV Excited Poling of Germanosilicate Fibre" OSA '95 Photosensitive nonlinearity in Glass waveguides - Fundamentals and Applications, OSA Technical Digest Vol. 22 1995. The fibre was fabricated by milling a pair of holes into the end face of a preform close to its core and positioned diametrically across the core with respect to one another. The preform was then drawn into fibre in a conventional manner so as to form a fibre with a core diameter of 8 µm and a spacing of 18 µm between the apertures that receive the electrodes. The apertures were of a diameter of the order of 70 µm and the electrodes wires had a diameter of the order of 50 µm. The electrode length was in one example 6 cm.

- 35 [0006] A disadvantage of this structure is that the electrodes need to be inserted into the fibre after formation. It will be seen that the electrode wires are of very small diameter and consequently difficult to handle. Furthermore, because the structures are so small, the electrodes have to be arranged to extend out of the apertures at opposite ends of the device in order to avoid risk of them touching, which therefore requires long connection leads. The entry of the leads in end faces of the fibre makes it very difficult to splice the fibre to conventional optical fibres, so that it cannot be included readily in optical circuits. Conventional fusion splicing could not be used because the heat required causes air in the holes to expand and distort or damage the heat softened glass of the fibre. Also, the holes need to be of a larger diameter than the electrode wires to allow them to be fitted, with the result that they are not held at a fixed distance from the core of the fibre. This can result in a non-uniform field being applied, in use, along the fibre.

- 45 [0007] Partial removal of the cladding of a fibre has been proposed in US 5 265 178 for the purpose of allowing a doped polymer to be placed close to the optical fibre for modulation purposes, rather than for applying a field to the core. Planar structures with modulating electrodes have been proposed in "Low-loss Strain Induced Optical Waveguides in Strontium Barium Niobate at 1.3µm wavelength", J. M. Marx et al Appl. Phys. Letts. 66 (3) January 1995, pp 274-276.

**Summary of the invention**

- [0008] The present invention provides an alternative, more robust structure for overcoming the aforesaid disadvantages of the prior art.

- 55 [0009] In accordance with the present invention, there is provided a fibre optic waveguide structure comprising: an elongate waveguide body including a core and cladding around the core, the body having an outer surface that includes a longitudinally extending recess and electrode means in the recess to apply an electric field across the core.

- [0010] Furthermore, in accordance with the present invention, there is provided a method of fabricating a waveguide

structure as is defined in claim 18 and an optical waveguide structure as is defined in claim 19.

[0011] The electrode means may comprise an elongate electrode support which extends into the recess and an electrically conductive region on the support extending along the length thereof. The support may include an elongate body member with an upstanding tongue that fits into the recess. The body may be made of glass and the conductive region may comprise a metallic coating formed on the glass.

[0012] Thus, in accordance with the invention, the electrodes may be readily fitted without the need to thread fine wires into apertures, which greatly simplifies manufacture.

[0013] Alternatively, the electrode means may comprise an electrically conductive layer on the first region, such as a metallisation layer, formed by evaporation techniques. The recess can be used to form a masking effect for the deposition, so as to allow the metal to be configured selectively on the first region.

[0014] The structure according to the invention has particular application to fibre optic waveguides that include a core and a cladding made of silica glass, wherein the core is doped with Ge or B, so as to render the structure photo-sensitive to u.v. light. However, the invention has wide application to many other material systems.

[0015] The structure according to the invention may be used with advantage as a phase modulator and can be made sufficiently small that a fibre structure is provided that can operate in single mode transmission.

[0016] Waveguides according to the invention may be formed by drawing from a preform, and the invention includes a method of fabricating a waveguide structure including: preparing a preform with material for forming a waveguide core surrounded by material for forming a waveguide cladding, the preform having an outer surface that includes first and second regions, the first region being closer to the core material than the second region, drawing the preform so as to produce a fibre optic waveguide with the same general cross sectional configuration as the preform but of extended length and reduced transverse dimensions, with the first and second regions running longitudinally of the length thereof, and providing an electrode that extends longitudinally over the first region of the outer surface.

[0017] The invention also includes a preform configured for use in this method.

## Brief description of the drawings

[0018] In order that the invention may be more fully understood an embodiment thereof will now be described by way of contrast with a prior art device as described by Fleming et al *supra*, reference being had to the accompanying drawings in which:

*Figure 1* is a cross-section through a prior art waveguide structure;

*Figure 2* is a longitudinal section of the device shown in *Figure 1*;

*Figure 3* illustrates a preform for use in manufacturing a waveguide structure in accordance with the invention;

*Figure 4* is a schematic perspective view of a short length of a waveguide and one of its associated electrode structures, in accordance with the invention;

*Figure 5* is a photograph of a section through a sample of a waveguide, corresponding to the waveguide shown in *Figure 4*;

*Figure 6* is a sectional view of the entire waveguide structure in accordance with an example of the invention;

*Figure 7* illustrates a fibre in accordance with the invention fusion spliced to conventional optical fibre at both ends;

*Figure 8* illustrates an alternative way of depositing an electrode in the recesses of the fibre;

*Figure 9* illustrates a fibre of *Figure 8*, after deposition of the electrodes and with the recesses filled with an insulating material;

*Figure 10* illustrates in cross section an alternative embodiment of optical fibre in accordance with the invention with a single generally rectangular recess;

*Figure 11* illustrates an alternative fibre in accordance with the invention, with a curved recess that includes a filamentary electrode;

*Figure 12* illustrates a cross section through a tape fibre in accordance with the invention;

*Figure 13* illustrates a transverse cross section of another tape fibre for the purposes of illustration only; and

*Figure 14* illustrates a cross section of a fibre in accordance with the invention with two recesses that enter the fibre from the same side.

## Detailed description

[0019] Referring to *Figures 1* and *2*, a prior art structure is shown, as disclosed by Fleming et al *supra*. A silica based fibre 1 which is shown in transverse cross section in *Figure 1*, has a core region 3 with a core diameter of 8  $\mu\text{m}$  surrounded by  $\text{SiO}_2$  cladding region 2 with an outer diameter of 125  $\mu\text{m}$ . The cladding region 2 has a lower refractive index than the core 3 such that light is guided along the core in a manner well known *per se*. The core also includes apertures 4, 5 which run longitudinally of the fibre and are positioned diametrically opposite to the core. The apertures

have a diameter of 70  $\mu\text{m}$  and receive electrode wires 7, 8 of diameter 50  $\mu\text{m}$ . The waveguide structure is formed by drawing from a preform of the same general shape as shown in Figure 1, in which the apertures 4, 5 are formed by drilling prior to the drawing process.

[0020] The waveguide structure has the advantage that the electrodes are placed close to the core. In one example, the hole spacing is 18  $\mu\text{m}$  so that a high field strength of 100 V/ $\mu\text{m}$  can be achieved.

[0021] However, there are a number of difficulties with this structure. The small diameter of the electrodes means that they are very difficult to handle mechanically and it is difficult to thread them into the apertures 4, 5. It would be desirable to have both electrodes extend from the same end of the structure but due to the small diameter, there is a significant risk that the bare electrode wires would touch one another and produce a short circuit. For this reason, it is usual to have the wires extend out of opposite ends as shown in Figure 2. A typical length for the structure is 6 cm with the result that the wires need to be brought together externally of the structure to a voltage source, with the disadvantage that bare electrode wires need to extend externally, which makes the device impractical. Also, because the electrode wires need to fit into the holes, they need to be a loose fit, with the result that their spacing from the core can vary along the length of the fibre. This can result in a non uniform electric field being applied across the core along the length of the fibre. Furthermore, because the electrode wires protrude from end faces of the fibre, it is difficult to splice the fibre with its protruding electrodes to conventional fibre. Fusion splicing would be problematic, due to the expansion of air in the holes 4,5 which would distort the soft glass produced by the heating used for conventional fusion splicing.

[0022] The present invention provides a solution to these problems.

[0023] Referring now to Figure 3, this shows a preform from which a waveguide for the structure according to the invention is made. The preform consists of a generally cylindrical block of silica glass 1 which includes a central Ge or Ge and B doped region 3 that defines material for a waveguide core of relatively high refractive index surrounded by region 2 with a low dopant concentration, that provides material for a surrounding cladding of the eventual waveguide. The preform is milled so as to form opposed parallel planar surface regions 9, 10. Recess regions 11, 12 extend from the planar surface regions 9, 10 towards the core region 3.

[0024] The preform is then drawn by conventional techniques to form an optical fibre and a short length of it is shown in Figure 4, referenced 13. It can be seen that the fibre has the same general shape as the preform although its dimensions are much reduced as it is of extended length as compared with the preform. When viewed in transverse cross section, the fibre has a relatively broad dimension  $b$  in a first direction and a relatively narrow dimension  $w$  in a second direction normal to the first direction. Two recesses 11, 12 of depth  $d$  extend from planar surface regions 9, 10 towards the core 3 along the length of the fibre, the recesses having a width  $e$ . The bottom of the recesses 14, 15 are spaced from the core by distances  $f_1, f_2$  respectively. The planar surface regions 9, 10 are connected by curved cylindrical surface regions 16, 18 that extend along the length of the fibre. An example of the dimensions of the structure are given in the following table.

parameter	$b$	$w$	$d$	$e$	$f_1$	$f_2$
dimension	250 $\mu\text{m}$	100 $\mu\text{m}$	30 $\mu\text{m}$	26 $\mu\text{m}$	9 $\mu\text{m}$	15 $\mu\text{m}$

[0025] The refractive index of the cladding material 2 in this example is 1.454 and the difference  $\delta n$  between the refractive index of the core and cladding is 0.01. A photograph of a sample of the waveguide is shown in Figure 5. From the foregoing it will be understood that the bottom of the recesses 11, 12 form first surface regions of the fibre optic waveguide body and the remainder of the outer surface of the body, namely the planar surface regions 9, 10 and the curved surface region 16, 17, form second surface regions which are disposed further away from the core than the first surface regions.

[0026] This structure has the advantage that an electrode can be placed in each of the recesses 11, 12, over the first surface regions, applied across the core 3. Furthermore, the electrodes can be placed at non-equal distances from the core, where  $f_1 \neq f_2$  in order to produce an asymmetrical electric field, if desired.

[0027] A suitable form of electrode structure 20 is shown in Figure 4 and comprises an elongate support made of u. v. transparent glass, which has been etched, milled, sawed or otherwise cut so as to form elongate symmetrical channels 21, 22 that define an upstanding tongue 23 on which is deposited a metallic coating 24. The metallic coating 24 may be deposited using conventional photolithography techniques, prior to the formation of the channels 21, 22. The support 20 has a width  $p$  and a height  $q$  with each of the channels 21, 22 being of a width  $r$  and depth  $s$ . An example of the dimensional parameters is set out in the table below.

parameter	$p$	$q$	$r$	$s$
dimension	5000 $\mu\text{m}$	5000 $\mu\text{m}$	113 $\mu\text{m}$	35 $\mu\text{m}$

[0028] It will be seen that the tongue 23 of the support 20 is dimensioned so as to fit into the recess 12.

[0029] A similar support is provided with a tongue that fits into recess 11 and the resulting structure is shown in cross section in Figure 6 in which the electrode supports are referenced 20a and b respectively. It can be seen from Figure 6 that the metallic layers 24a, b can readily be inserted into the recesses 11, 12 so as to be disposed in close proximity with the core and thereby enable an electric field to be developed across the core to alter its optical characteristics. The metallic layers 24a, b can be run at the ends of the supports 20a, b onto exterior surfaces 25a, b over side edges of the supports so as to provide external contact pads for providing a convenient external connection.

[0030] It will be appreciated that assembly of the structure is relatively simple as compared with the described prior art because the component parts merely need to be pushed together with no complex threading of electrodes as hitherto.

[0031] As previously described, the core 3 of the structure is photosensitive to u.v. light. When doped with Ge or B, it is photosensitive to radiation with a wavelength of 244 nm. Consequently, if desired, a refractive index Bragg grating can be written into the core e.g. using a phase mask. Reference is directed to G. Meltz et al "Formation of Bragg Gratings in Optical Fibres by Transverse Holographic Method" Opt. Lett. Vol. 14, No. 15, 823 (1989). Furthermore, a poled structure can be recorded in the fibre, by recording a u.v. pattern with an electric field applied between the electrodes formed by the layers 24a, b in the manner described in Fujiwara et al, *supra*. Further details of fibre poling methods can be found in "Phase material second-harmonic generation by periodic poling of fused silica" R. Kashyap et al, Appl. Phys. Lett. 64(11), 14 March 1994 pp 1332-1334; "High second-order nonlinearities in poled silicate fibres" P.G. Kazansky et al, Optics Letters, 15 May 1994, Vol. 19, No. 10, pp 701-703 and "Electro-optic phase modulation in a silica channel waveguide", A.C. Liu et al, Optics Letters, Vol. 19, No. 7, 1 April 1994, pp 466-468. The resulting refractive index grating can then be tuned by the application of a electric field which alters the refractive index of the core by applying a voltage to the metallic layers 24a, b. Furthermore, the device can be used as a phase modulator when no Bragg grating is recorded. The applied field alters the refractive index of the core and thus introduces a phase shift for optical signals travelling along the fibre. This can be used with advantage in a Mach Zehnder interferometer or in other optical devices.

[0032] The structure according to the invention has the advantage that it can be manufactured in long lengths e.g. 50 cm or more whereas in the prior art, it was difficult to construct devices longer than 10 cm.

[0033] The structure can readily be spliced to conventional optical waveguides and Figure 7 shows a length of the waveguide structure 30 constructed as described with reference to Figure 6, spliced to lengths 31, 32 of silica based optical fibre. Fusion splices are formed at 33 and 34 by conventional techniques well known to those skilled in the art. Electrode wires 35, 36 are connected to the metallic layers a,b which are run onto the surfaces a,b as described with reference to Fig. 6. Thus, the ends of the structure are free of electrode wires and can be joined by fusion splicing or other conventional butt joining techniques to optical fibres 31, 32. In Figure 7 the wires 35, 36 are shown at the same end of the waveguide structure, but they could be at opposite ends.

[0034] An alternative way forming the electrode structures is shown in Figures 8 and 9. In this example, metallisation layers are formed directly within the recesses 11, 12. Referring to Figure 8, gold is evaporated by conventional techniques, using a resistive heater 37 driven by an electrical power source 38 in a vacuum chamber (not shown). Au vapour travels in the direction of arrows 39 so as to become deposited on the first surface region, namely the bottom of recess 12. Similar deposition is carried out on the bottom of recess 11. A gold layer is not significantly deposited on the side walls of the recesses 11, 12 but deposition does occur on the planar surfaces 9, 10. The Au layer on surfaces 9, 10 is removed subsequently either by rubbing or by using a self-adhesive tape applied to the surfaces to lift off the gold. Thus, the recesses 11, 12 can be used to self-mask the deposited electrodes.

[0035] Thus, referring to Figure 9, metallisation layers 40a, b formed of the deposited Au material extend along the bottom of the recesses 11, 12 so as to provide the electrodes. Thereafter, the recesses may be filled with a suitable material 41, such as an electrically insulating compound such as silicon rubber so as to protect the fibre from dielectric breakdown and flash-over. This configuration has the advantage that separate glass electrode structures as shown in Figure 4 do not need to be fitted to the fibre. It will be understood that other metallisation layers could be used, instead of Au. Also, non-metallic electrically conductive materials may be used, such polycrystalline silicon.

[0036] Many different, specific designs of fibre fall within the scope of the invention and a number of alternatives will now be described by way of example.

[0037] Referring to Figure 10, an alternative fibre cross section in accordance with the invention is shown, which includes a single rectangular recess 42 containing a metallic deposited electrode 43, formed in the manner described with reference to Figures 8 and 9. A second electrode 44 is formed by a vapour deposition on a planar surface 45 on the opposite side of the fibre 2 to the electrode 43. It will be understood that the fibre is drawn from a correspondingly shaped preform of large dimensions in the manner previously described with reference to Figure 3, 4 and 5. The edges of the second electrode 44 may be defined by selectively rubbing the curved surfaces 16, 17 of the fibre to remove any deposited metallic material therefrom, so as to leave the materials selectively on the surface 45. Alternatively, a suitable conventional masking technique may be used during the vapour deposition process.

[0038] Referring to Figure 11, another version of the fibre is shown, which is similar to that of Figure 10, in which the lowermost electrode 44 is formed on a planar surface 45 in the manner previously described. However, recess 46 has a generally curved cross section and the electrode 47 is formed by a filamentary element which is physically fitted within the recess 46. It will be understood that the fitting of the element 47 is much simpler than in the prior art because it is not necessary actually to thread the element through an aperture; instead it is laid in the recess 46 from outside the fibre. Furthermore, since only one filamentary element 47 is used, the possibility of it touching the other electrode 44 is materially reduced.

[0039] Referring to Figure 12, the optical fibre is in the form of a tape of cross sectional width dimension  $w = 50\mu\text{m}$  and a cross sectional breadth dimension  $b = 1\text{mm}$ . The tape fibre includes longitudinal recesses 47, 48 that extend from the outer surface of the waveguide body towards the core 3 of the fibre, on opposite sides thereof. The base of each of the recesses 47, 48 is coated with a metallic, deposited conductive layer 49, 50 to form electrodes which allow an electric field to be applied across the core 3. As shown in Figure 12, the core may be disposed asymmetrically between the electrodes 49, 50. A typical example of the diameter of the core is  $8\mu\text{m}$ .

[0040] An alternative arrangement, which is shown for the purposes of illustration only, and does not fall under the scope of the claims, is shown in Figure 13, in which the tape fibre has the same dimensions as shown in Figure 12 but instead of providing recesses, the electrodes comprise metallisation layers 51, 52 formed on the exterior body of the waveguide, on first surface regions 53, 54 that are closer to the core than opposed second regions 55, 56. It will be seen that the core 2 is disposed asymmetrically between the electrodes 51, 52.

[0041] Referring to Figure 14, another fibre optic waveguide cross section is shown, which includes a flat surface 45, corresponding to the surface shown in Figure 11, together with first and second recesses 55, 56, which extend from the same side of the fibre, in parallel, on opposite sides of the core 3, into the cladding region 2.

[0042] It will be understood that all of the embodiments shown in Figures 10 to 14 are formed by drawing from a preform of corresponding shape, in the manner generally described with reference to Figure 3 and 4. The preform for each of the embodiments of Figures 10 to 14 may be made of materials as described with reference to Figure 3 and the core dimension may be generally similar also.

[0043] Many modifications and variations of the described inventive structure are possible. For example it would be possible to construct a device including two cores spaced apart in a common cladding, each having an associated pair of recesses such as 11 and 12 shown in Figure 6, and the electrode supports 20 having more than one tongue so as to fit into the recesses for each of the cores.

[0044] Furthermore, whilst the device has been described in relation to the a germanosilicate fibre, the invention is not limited to these materials and can be used with any suitable material that exhibits an electro-optic characteristic.

## Claims

1. A fibre optic waveguide structure comprising:

an elongate waveguide body including a core (3) and cladding (2) around the core,  
the body having an outer surface that includes a longitudinally extending recess (11, 12), and  
electrode means (40a, 40b) in the recess to apply an electric field across the core.

2. A structure according to claim 1 wherein the electrode means comprises an electrically conductive layer in the recess.

3. A structure according to claim 1 or 2 wherein the electrode means includes an elongate electrode support in the recess, and an electrically conductive region on the support extending along the length thereof.

4. A structure according to claim 3 wherein the support includes an elongate body member with an upstanding tongue which fits into the recess along the length thereof.

5. A structure according to claim 3 or 4 wherein the support is made of glass and the conductive region comprises a metallic coating formed on the glass.

6. A structure according to any preceding claim wherein the waveguide, in transverse cross section, has a relatively broad dimension ( $b$ ) in a first direction and a relatively narrow dimension ( $w$ ) in a second direction extending transversely of the first direction, and the recess extends inwardly from the exterior of the cladding towards the core in said second direction.

7. A structure according to claim 6 wherein said broad dimension ( $b$ ) is about 250  $\mu\text{m}$ , said narrow dimension ( $w$ ) is about 100 $\mu\text{m}$ , and the recess has a depth ( $d$ ) of about 30  $\mu\text{m}$ .
8. A structure according to any preceding claim including first and second of said recesses, and first and second of said electrode means in the recesses respectively, the core being disposed between the electrode means.
9. A structure according to claim 8 wherein the outer surface has an external surface which includes planar surface regions which extend longitudinally of the waveguide, and generally cylindrical surface regions which extend between the opposed planar regions, the recesses being disposed in the planar regions respectively so as to extend towards the core.
10. A structure according to claim 8 wherein the outer surface of the cladding includes longitudinal planar surface regions and curved generally cylindrical surface regions which extend between the opposed planar regions, the recesses being formed in the planar regions respectively so as to extend towards the core.
11. A structure according to any preceding claim wherein the waveguide is formed of silica glass that has been doped to provide the core.
12. A structure according to claim 11 wherein the core dopant includes Ge and B.
13. A structure according to any preceding claim configured to operate as a phase modulator.
14. A structure according to any preceding claim operable in single mode transmission.
15. A structure according to any preceding claim, coupled at an end thereof to another fibre optic waveguide.
16. A structure according to claim 15 wherein the coupling comprises a fusion splice.
17. A structure according to any preceding claim including a grating in the fibre.
18. A method of fabricating a waveguide structure including:
  - preparing a preform with material for forming a waveguide core surrounded by material for forming a waveguide cladding, the preform having an outer surface that includes a recess,
  - drawing the preform so as to produce a fibre optic waveguide with the same general cross sectional configuration as the preform but of extended length and reduced transverse dimensions, with the recesses running longitudinally of the length thereof, and
  - providing an electrode that extends longitudinally in the recess to apply an electric field to the core.
19. An optical waveguide structure comprising:
  - an elongate generally cylindrical light guiding waveguide body having a longitudinal outer surface, that includes material which has been photo-excited to a poled condition so as to exhibit an electro-optic coefficient, and
  - electrode means for applying an electric field into the waveguide body to alter said electro-optic coefficient, wherein the longitudinal outer surface includes at least one longitudinal recess, and the electrode means is disposed in the recess to apply the electric field into the waveguide body along the length thereof.

## Patentansprüche

### 1. Optische Wellenleiterfaserstruktur mit:

einem länglichen Wellenleiterkörper mit einem Kern (3) und einer Hülle (2) um den Kern, wobei der Körper eine äußere Oberfläche hat, die eine sich longitudinal erstreckende Aussparung (11, 12) aufweist, und eine Elektrodevorrichtung (40a, 40b) in der Aussparung für das Anlegen eines elektrischen Feldes über den Kern.

2. Struktur nach Anspruch 1, bei der die Elektrodevorrichtung eine elektrisch leitende Schicht in der Aussparung aufweist.
3. Struktur nach Anspruch 1 oder 2, bei der die Elektrodevorrichtung einen länglichen Elektrodenträger in der Aussparung und einen elektrisch leitenden Bereich auf dem Träger, der sich über die Länge davon erstreckt, umfaßt.
4. Struktur nach Anspruch 3, bei der der Träger ein längliches Körpersegment mit hochstehender Zunge umfaßt, welche in die Aussparung entlang deren Länge paßt.
5. Struktur nach Anspruch 3 oder 4, bei der der Träger aus Glas besteht und der leitende Bereich eine metallische Beschichtung auf dem Glas umfaßt.
6. Struktur nach einem der vorangehenden Ansprüche, bei der der Wellenleiter im transversalen Querschnitt eine relativ breite Ausdehnung (b) in einer ersten Richtung und eine relativ schmale Ausdehnung (w) in einer zweiten Richtung transversal zu der ersten Richtung aufweist und die Aussparung sich von außerhalb der Beschichtung in der zweiten Richtung nach innen zum Kern erstreckt.
7. Struktur nach Anspruch 6, bei der die breite Ausdehnung (b) etwa 250 µm beträgt, die schmale Ausdehnung (w) etwa 100 µm beträgt und die Aussparung eine Tiefe (d) von etwa 30 µm aufweist.
8. Struktur nach einem der vorangehenden Ansprüche mit erster und zweiter Aussparung und erster und zweiter Elektrodevorrichtung in der jeweiligen Aussparung, bei der der Kern zwischen den Elektrodevorrichtungen angeordnet ist.
9. Struktur nach Anspruch 8, bei der die äußere Oberfläche eine externe Oberfläche aufweist, welche planare Oberflächenbereiche, die sich longitudinal zum Wellenleiter erstrecken, und allgemein zylindrische Oberflächenbereiche umfaßt, die sich zwischen den gegenüberliegenden planaren Bereichen erstrecken, wobei die Aussparungen jeweils in den planaren Bereichen angeordnet sind, so daß sie sich zum Kern hin erstrecken.
10. Struktur nach Anspruch 8, bei der die äußere Oberfläche der Beschichtung longitudinale planare Oberflächenbereiche und gekrümmte, allgemein zylindrische Oberflächenbereiche umfaßt, die sich zwischen den gegenüberliegenden planaren Bereichen erstrecken, wobei die Aussparungen jeweils in den planaren Bereichen ausgebildet sind, so daß sie sich zum Kern hin erstrecken.
11. Struktur nach einem der vorangehenden Ansprüche, bei der der Wellenleiter aus Quarzglas besteht, das zum Herstellen des Kerns dotiert ist.
12. Struktur nach Anspruch 11, bei der der Dotierstoff des Kerns Ge und B beinhaltet.
13. Struktur nach einem der vorangehenden Ansprüche, die so aufgebaut ist, daß sie als Phasenmodulator arbeitet.
14. Struktur nach einem der vorangehenden Ansprüche, die bei Einzelmodenübertragung einsetzbar ist.
15. Struktur nach einem der vorangehenden Ansprüche, die an einem ihrer Enden an einen anderen faseroptischen Wellenleiter gekoppelt ist.
16. Struktur nach Anspruch 15, bei der das Koppeln Fusions-Spleißen beinhaltet.
17. Struktur nach einem der vorangehenden Ansprüche mit einem Gitter in der Faser.
18. Verfahren zum Herstellen einer Wellenleiterstruktur mit:
 

Erzeugen einer Vorform aus Material für das Erzeugen eines Wellenleiterkerns, der von Material für das Bilden einer Wellenleiterbeschichtung umgeben ist, wobei die Vorform eine äußere Oberfläche aufweist, die eine Aussparung aufweist,

Ziehen der Vorform, so daß ein faseroptischer Wellenleiter mit derselben allgemeinen Querschnittskonfiguration wie der Vorform aber mit größerer Länge und kleineren transversalen Dimensionen erzeugt wird, wobei die Aussparungen sich longitudinal über die Länge davon erstrecken, und



Herstellen einer Elektrode, die sich longitudinal in der Aussparung für das Anlegen eines elektrischen Feldes an den Kern erstreckt.

19. Optische Wellenleiterstruktur mit:

einem länglichen, allgemein zylindrischen lichtführenden Wellenleiterkörper mit einer longitudinalen äußeren Oberfläche, die Material beinhaltet, die photoangeregt ist, bis eine Pole-Bedingung erreicht wird, so daß sich ein elektrooptischer Koeffizient ergibt, und eine Elektrodevorrichtung für das Anlegen eines elektrischen Feldes in dem Wellenleiterkörper, um den elektrooptischen Koeffizienten zu verändern, wobei die longitudinale äußere Oberfläche wenigstens eine longitudinale Aussparung aufweist und die Elektrodevorrichtung in der Aussparung angeordnet ist für das Anlegen des elektrischen Feldes in dem Wellenleiterkörper entlang dessen Längsausdehnung.

Revendications

1. Structure de guide d'ondes optiques à fibre comprenant :

un corps de guide d'ondes allongé comprenant un coeur (3) et une gaine (2) autour du coeur, le corps présentant une surface extérieure qui comprend un évidement s'étendant longitudinalement (11, 12), et un moyen d'électrode (40a, 40b) dans l'évidement pour appliquer un champ électrique au travers du coeur.

2. Structure selon la revendication 1, dans laquelle le moyen d'électrode comprend une couche électriquement conductrice dans l'évidement.

3. Structure selon la revendication 1 ou 2, dans laquelle le moyen d'électrode comprend un support d'électrode allongé dans l'évidement, et une région électriquement conductrice sur le support s'étendant sur la longueur de celui-ci.

4. Structure selon la revendication 3, dans laquelle le support comprend un élément de corps allongé avec une languette dressée qui s'adapte dans l'évidement sur la longueur de celui-ci.

5. Structure selon la revendication 3 ou 4, dans laquelle le support est constitué de verre et la région conductrice comprend un revêtement métallique formé sur le verre.

6. Structure selon l'une quelconque des revendications précédentes, dans laquelle le guide d'ondes, en section transversale, présente une dimension relativement large (b) dans une première direction et une dimension relativement étroite (w) dans une seconde direction s'étendant transversalement par rapport à la première direction, et l'évidement s'étend vers l'intérieur depuis l'extérieur de la gaine vers le coeur dans ladite seconde direction.

7. Structure selon la revendication 6, dans laquelle ladite dimension large (b) est d'environ 250  $\mu\text{m}$ , ladite dimension étroite (w) est d'environ 100  $\mu\text{m}$ , et l'évidement présente une profondeur (d) d'environ 30  $\mu\text{m}$ .

8. Structure selon l'une quelconque des revendications précédentes, comprenant un premier et un second dudit évidement, et un premier et un second dudit moyen d'électrode dans les évidements, respectivement, le coeur étant disposé entre les moyens d'électrode.

9. Structure selon la revendication 8, dans laquelle la surface extérieure présente une surface externe qui comprend des régions de surface planes qui s'étendent longitudinalement par rapport au guide d'ondes, et des régions de surface généralement cylindriques qui s'étendent entre les régions planes opposées, les évidements étant disposés dans les régions planes, respectivement, de façon à s'étendre en direction du coeur.

10. Structure selon la revendication 8, dans laquelle la surface extérieure de la gaine comprend des régions de surface longitudinales planes et des régions de surface généralement cylindriques courbes qui s'étendent entre les régions planes opposées, les évidements étant formés dans les régions planes, respectivement, de façon à s'étendre en direction du coeur.

11. Structure selon l'une quelconque des revendications précédentes, dans laquelle le guide d'ondes est formé de verre de silice qui a été dopé pour réaliser le coeur.

12. Structure selon la revendication 11, dans laquelle le dopant du coeur comprend Ge et B.

13. Structure selon l'une quelconque des revendications précédentes, configurée pour fonctionner comme modulateur de phase.

14. Structure selon l'une quelconque des revendications précédentes, pouvant être mise en oeuvre dans une transmission monomode.

15. Structure selon l'une quelconque des revendications précédentes, couplée à une extrémité de celle-ci à un autre guide d'ondes à fibre.

16. Structure selon la revendication 15, dans laquelle le couplage peut comprendre une épissure par fusion.

17. Structure selon l'une quelconque des revendications précédentes, comprenant un réseau de diffraction dans la fibre.

18. Procédé de fabrication d'une structure de guide d'ondes comprenant :

la préparation d'une préforme avec un matériau destiné à former un coeur de guide d'ondes entouré d'un matériau destiné à former une gaine de guide d'ondes, la préforme présentant une surface extérieure qui comprend un évidement,

l'étirage de la préforme de façon à produire un guide d'ondes optiques à fibre présentant la même configuration générale en section transversale que la préforme mais de longueur étendue et de dimensions transversales réduites, les évidements courant longitudinalement sur la longueur de celle-ci, et  
la fourniture d'une électrode qui s'étend longitudinalement dans l'évidement en vue d'appliquer un champ électrique au coeur.

19. Structure de guide d'ondes optiques comprenant :

un corps de guide d'ondes de guidage de lumière généralement cylindrique allongé présentant une surface extérieure longitudinale qui comprend un matériau qui a été photo-excité dans une condition polarisée de façon à présenter un coefficient électro-optique, et  
un moyen d'électrode destiné à appliquer un champ électrique dans le corps du guide d'ondes afin de modifier ledit coefficient électro-optique, dans lequel la surface extérieure longitudinale comprend au moins un évidement longitudinal, et le moyen d'électrode est disposé dans l'évidement afin d'appliquer le champ électrique dans le corps du guide d'ondes sur la longueur de celui-ci.

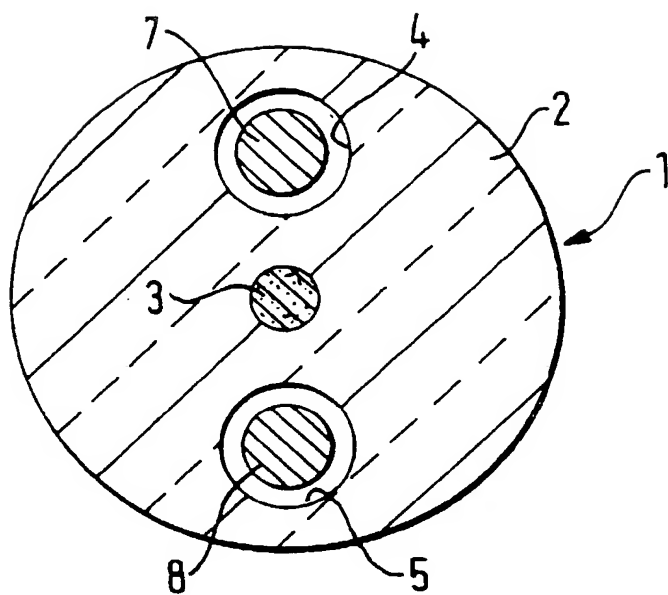


FIG. 1  
PRIOR ART

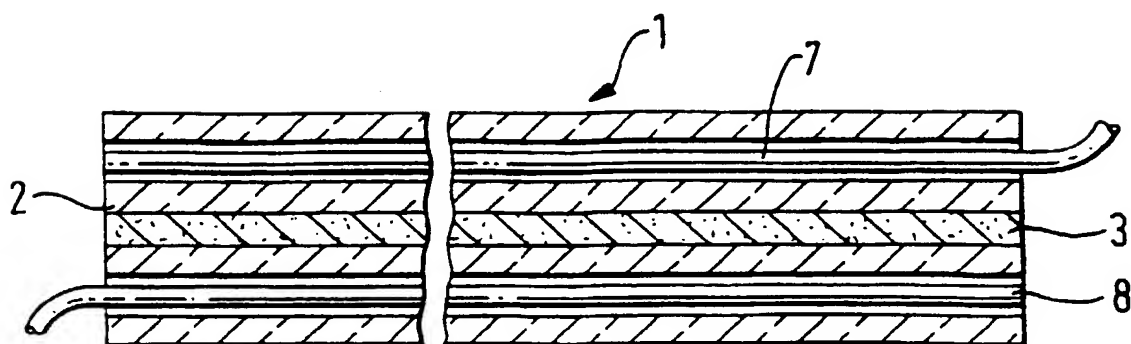


FIG. 2  
PRIOR ART

FIG. 3

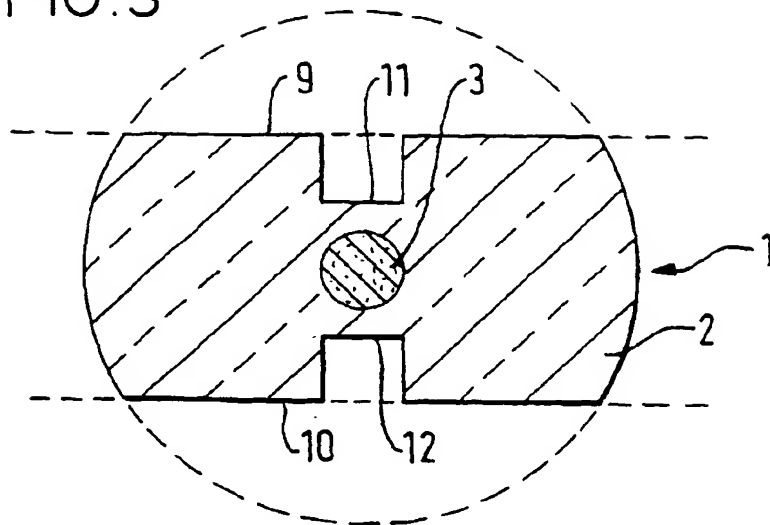


FIG. 4

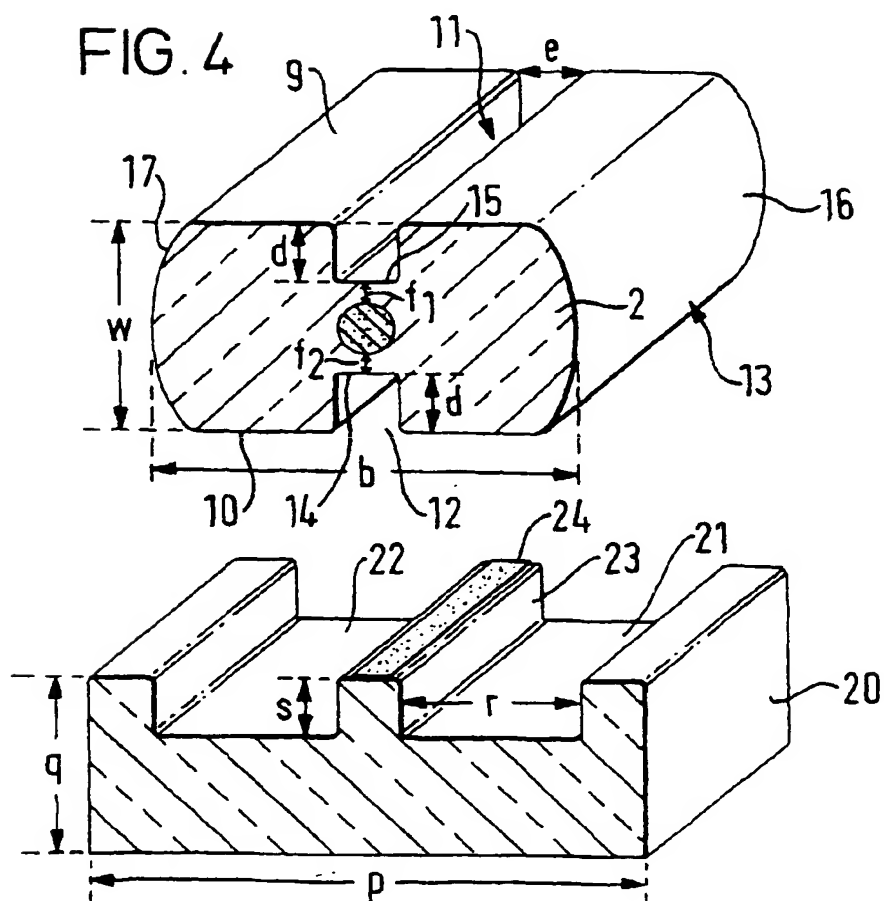
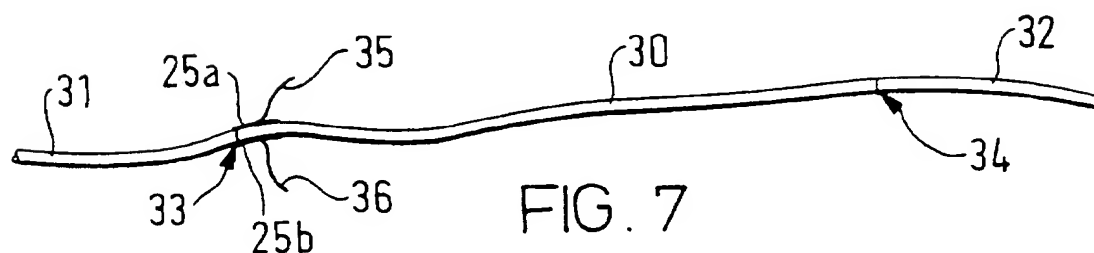
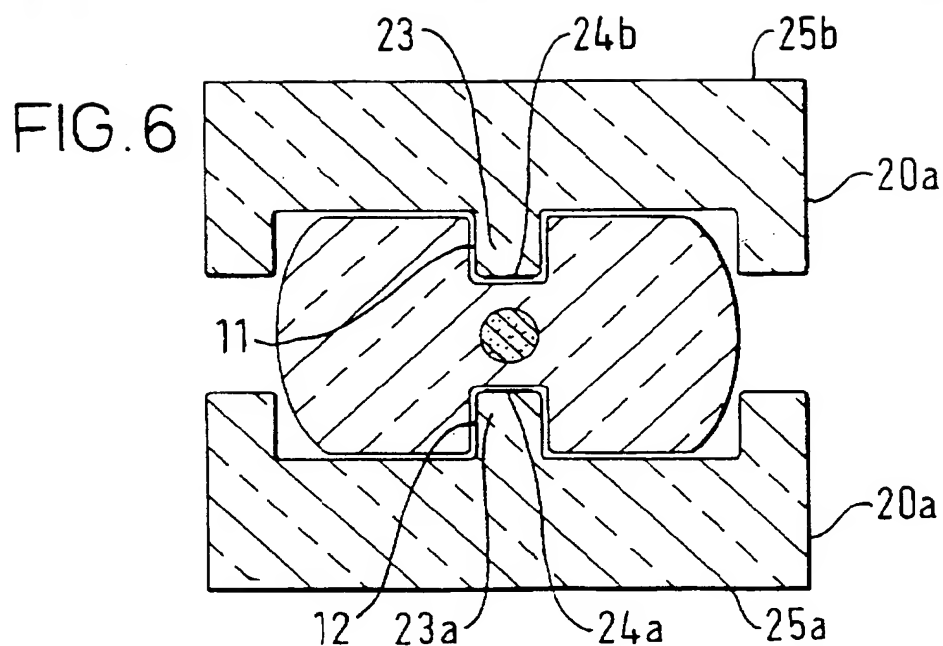
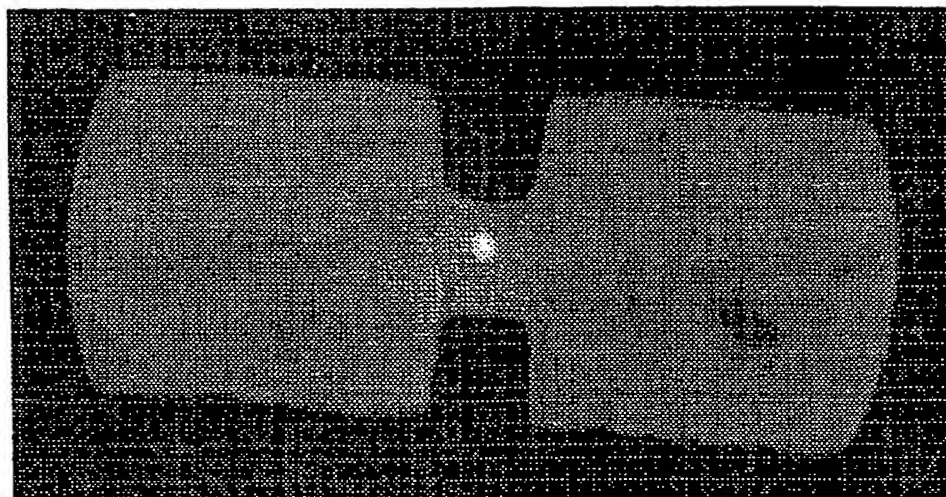


FIG. 5.



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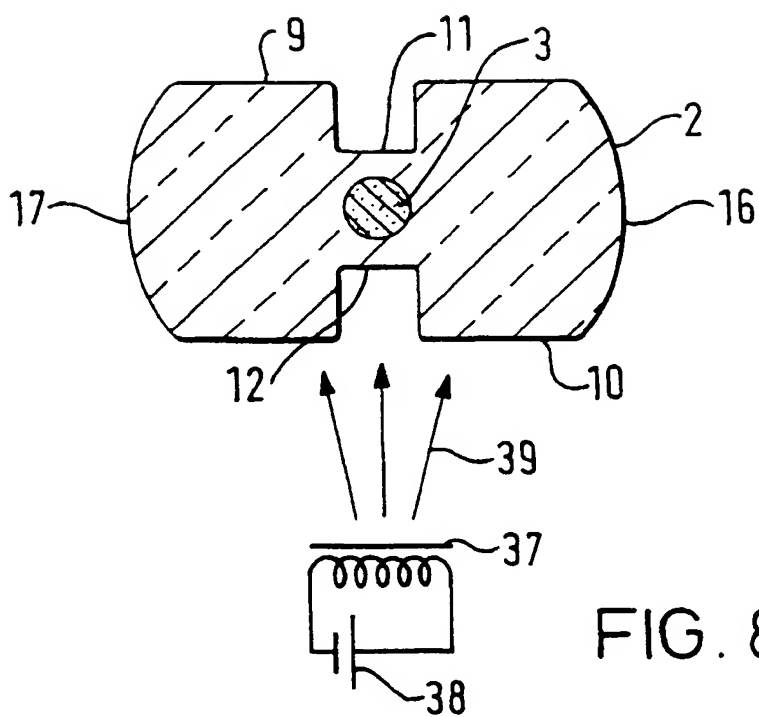


FIG. 8

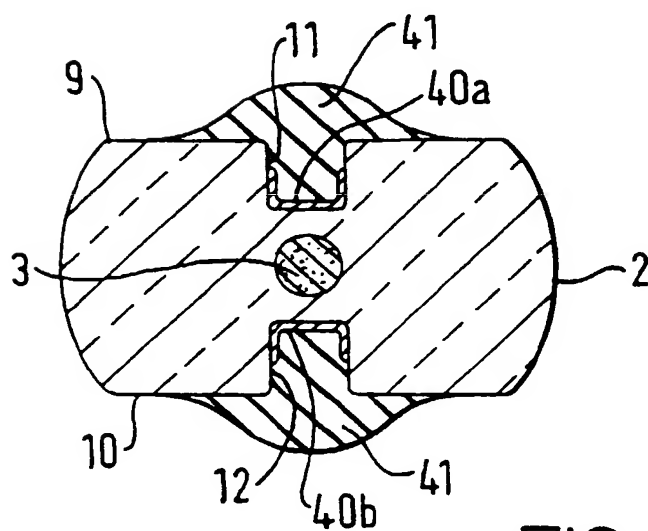


FIG. 9

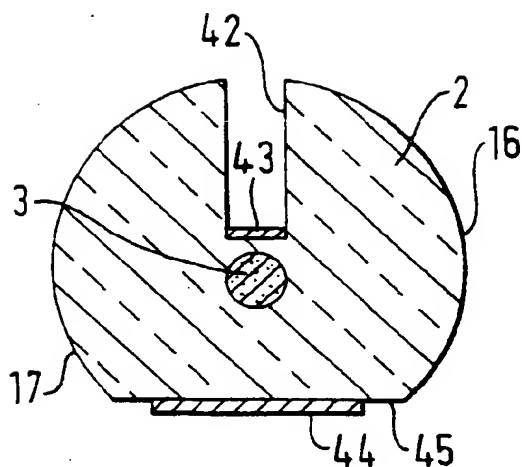


FIG. 10

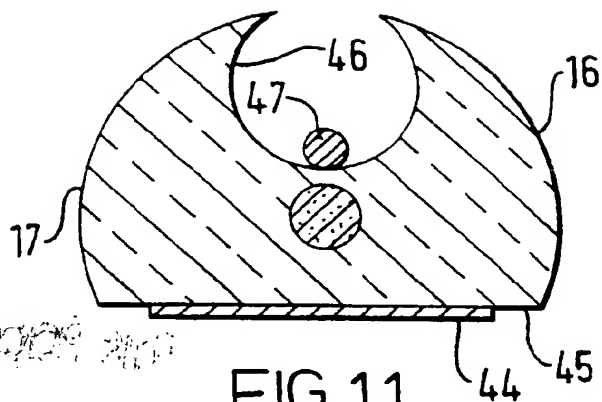


FIG. 11

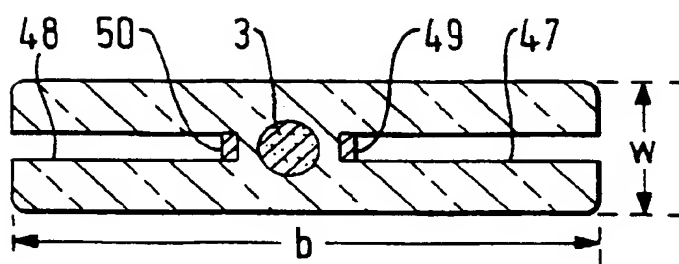


FIG. 12

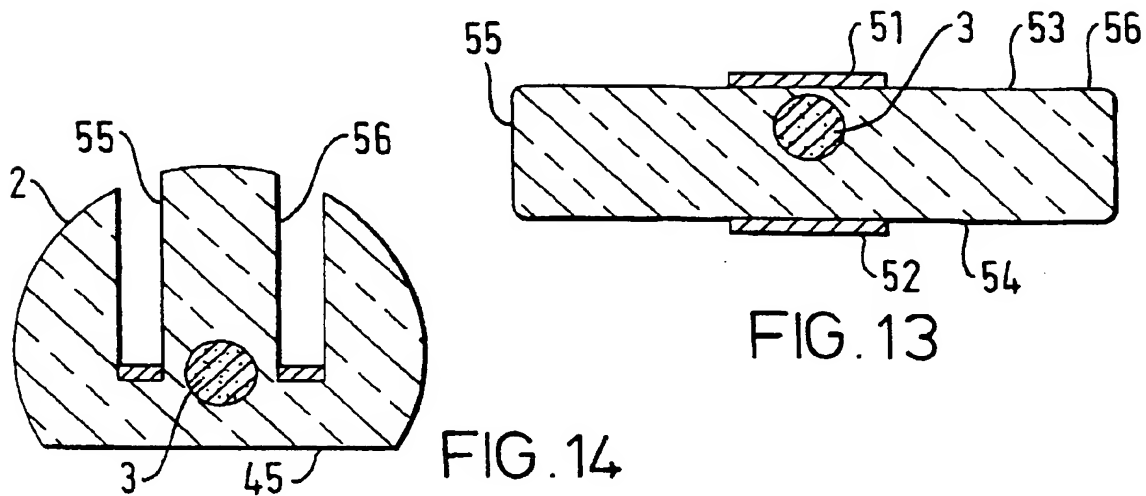


FIG. 13

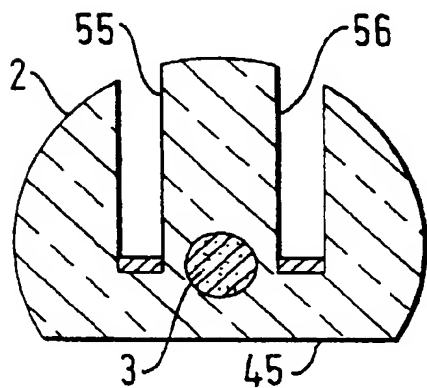


FIG. 14

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